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BERLAGE ON EAST MONSOON FORECASTING FOR JAVA [1]

By Alfred J. Henry

The author points out that curves representing the monthly mean deviations of the meteorological elements from the normal over an extensive area, that includes Australia, the Malay Archipelago, and probably the whole of the Indian Ocean, show a fairly regular periodicity in which a three-year cycle is prominent.

Like all other periodicities thus far discovered, this one breaks down; some disturbing influence reduces the amplitude of the deviations, or even destroys them altogether. The best examples of regular epochs of maximum pressure are those of 1885, 1888, 1891, and 1896, 1899, 1902, respectively, with a break between

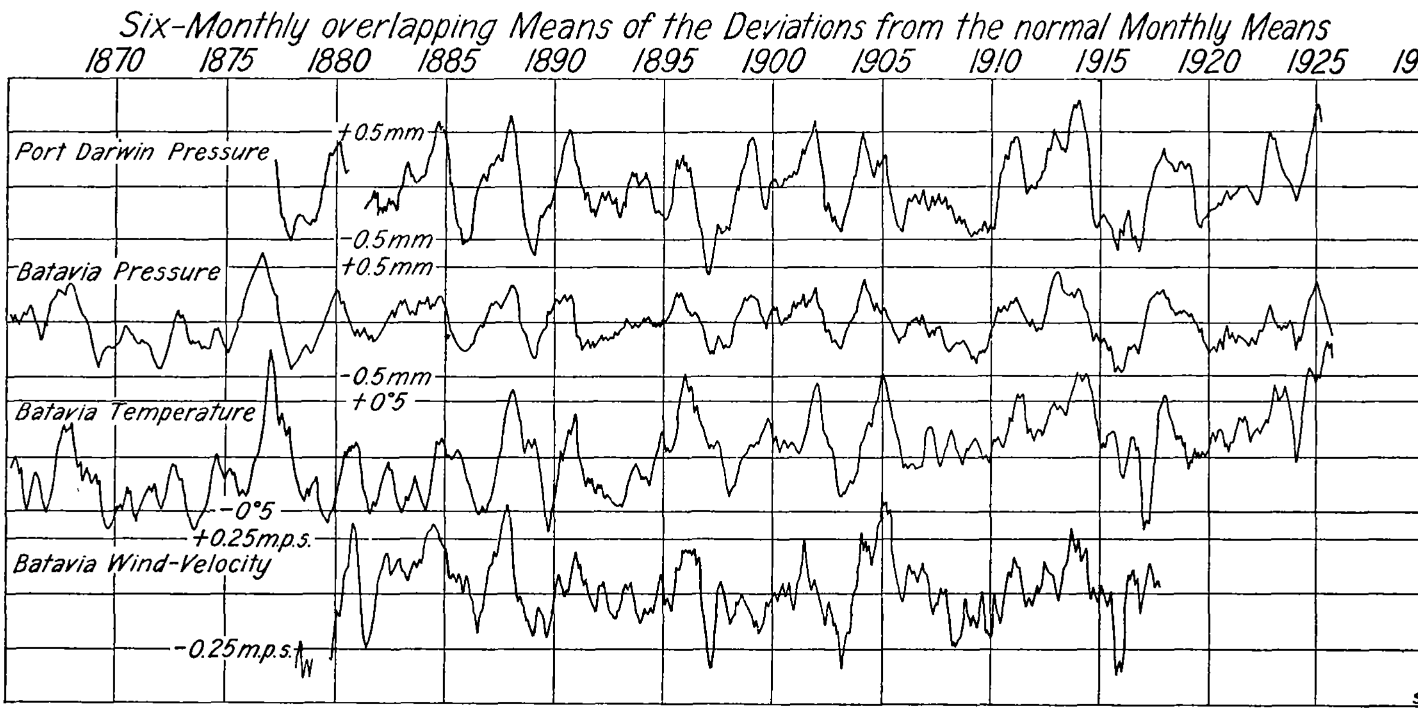

Fig. 1

Figure 1 contains a number of curves showing the march of pressure and temperature at Batavia over a period of 65 years, and for a shorter interval for other elements.

The Port Darwin pressure curve, for reasons given by Braak (1), is unique in that pressure passes from a maximum to a minimum and then to a second maximum within a period of three years.

1891 and 1896. Another series of oscillations with a distinct three-year period gave maxima in 1911 and 1914, and one might find a regular succession of maxima separated by intervals of three years from 1896 up to 1914, but from the 1914 maximum up to the present date the three-year period seems entirely lost; there is, however, one important maximum at the close of 1918, and others follow in 1923 and 1925.

[1] Koninklijk Magnetisch en Meteorologisch Observatorium te Batavia Verhandelingen No. 20. 1927.

The author suggests that the influences which interrupt the regular waves are in some way connected with the relative sun-spot numbers. Epochs of sun-spot maxima are characterized by a damping of the air pressure curve, as may be seen from the Port Darwin trace for sun-spot maxima of 1883 and 1893. It may also be seen from this curve that no prominent maxima occur therein between 1881 and 1885 and between 1891 and 1896. The tendency is less clearly shown at sun-spot maximum of 1905 and 1917, yet shortly after 1905 air pressure remained below normal for several years, and the 1918 maximum rises out of one of the most striking depressions of the curve.

The Batavia pressure curve, the second from the top, is quite similar to Port Darwin, although the amplitude of Port Darwin deviations is almost twice as great as those of Batavia.

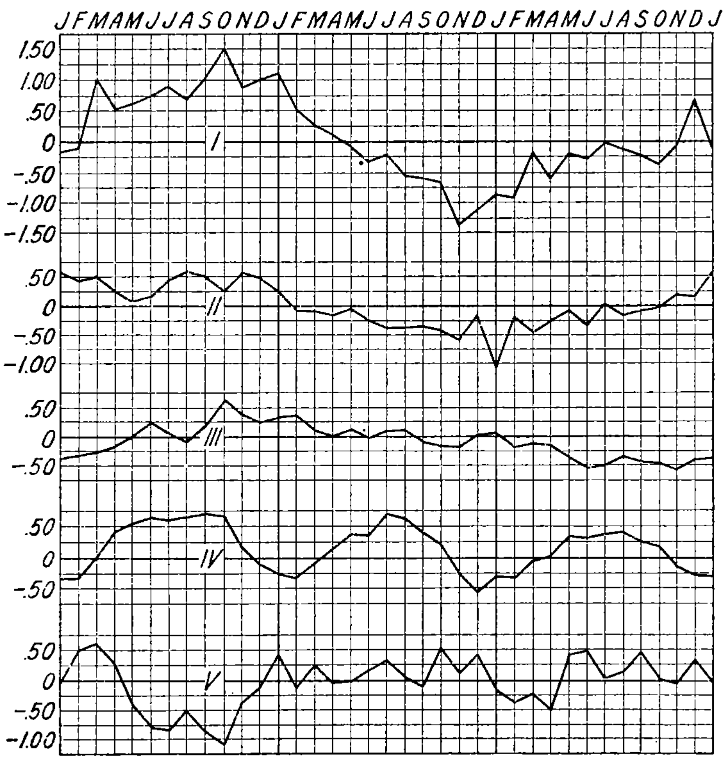

FIG. 2.—Deviations from the normal monthly means in the course of the three-year cycle

I. Port Darwin pressure, millimeters
II. Batavia pressure, in millimeters
III. Batavia temperature, in degrees Celcius
IV. East component of wind at Batavia in miles per second
V. Rainfall in West Java, in millimeters

Braak has already pointed out that a close correlation exists between the deviations of air pressure and those of other meteorological elements. (See fig. 1.)

Since the three-year cycle is a prominent feature of the different curves Doctor Berlage asks what is the normal type of such a cycle? The series of waves showing maxima in 1885, 1888, 1891 is the one that is least disturbed. It shows rapid falls in 1886, 1889, 1892, while the barometer takes two years to rise from one minimum to the next maximum, thus suggesting that we can not adequately represent the oscillations by a simple harmonic one. How far this is the case is best shown by taking the means of the corresponding monthly deviations in each wave. These "quasi-normal" values are shown by the curves of Figure 2.

The first year of the cycle is a high-pressure year at both Port Darwin and Batavia; it may, however, open with pressure below normal at Port Darwin and above normal at Batavia. In a normal cycle a high-pressure year is followed by a year of falling barometer (transition year) and this again by one of rising barometer.

During the high-pressure year temperature rises and attains its maximum at the close of the year at the very moment of maximum pressure. Then follows two years of gradually falling temperature and a minimum is reached at the close of the third year.

While the pressure and temperature curves have not the same shape, they strongly suggest that the pressure-deviations are followed by temperature deviations of the same sign.

The east monsoon of the three successive years are characterized by decreasing wind force, the strongest east winds corresponding with the maximum of the pressure curve. The strongest west winds occur at the time of minimum pressure, i. e. in the west monsoon preceding the wet year. The high-pressure year is characterized by a very dry east monsoon, the next year by a wet east monsoon. As a normal east monsoon is also a dry season we find here the basis for the public opinion that two dry east monsoons are generally followed by a wet east monsoon. Abnormally high rainfall occurs in the west monsoon preceding the abnormally dry and persistent east monsoon. The relatively driest west monsoon is the one which corresponds with the barometric minimum and strongest west winds.

The author stresses the relations between air pressure, temperature, and rainfall. He says:

> I wish to emphasize how intimately air pressure, temperature, and rainfall are related. Of course all special cases of the three-year cycle show important deviations from the normal one. However, it may be easily understood that the disappearance of the three-year period in later years was a great drawback in trying to forecast monsoon rainfall.

Considering the general connection between air pressure and temperature, the author quotes Braak as follows:

> The connection may be expressed as follows: The pressure deviations are followed by temperature deviations of the same sign. The former should in this case be regarded as the cause of the latter. The result is less satisfactory if we try to describe the pressure variations as a consequence of the temperature changes, assuming the latter ones to be followed by pressure changes of opposite sign. This explanation falls short especially in periods of disturbance, when the low pressure has no counterpart in an excess of temperature.

Braak further concludes:

> The very close connection between the pressure and temperature variations can not be explained by means of the intermediate action of rainfall or cloudiness ... . In order to explain the strong connection between pressure and temperature, we shall therefore have to look for still another cause which must be of very general character. (1 idem, p. 25.)

Relation of sea to air temperature.—The author postulates the almost self-evident fact that the close parallelism between Batavia temperature and Indian Ocean temperature indicates that Batavia temperature is greatly dominated by sea temperature and he expresses the relation in the form of an equation as follows:

$$T(t) = aP(t - t_0) \qquad (1)$$

Deviation of sea surface temperature from the normal at time t is denoted by $T(t)$, atmospheric pressure by $P(t)$, and the lag of time between corresponding deviations of both elements, assuming it to be constant, by t_0, as in the above formula. Temperature variations in the sea surface throughout the Archipelago are, however, not uniform. Braak discovered a second type in the eastern half, as indicated in the next following paragraph.

When this curve for the eastern part is compared with the Batavia curve it appears that the difference between them arises principally from the fact that a number of waves, which are of quite secondary importance in the Batavia curve, have developed into waves of primary importance in the Makassar-Bima curve (not reproduced). They already exist, however, in the initial state of development in the Batavia variations.

Interpretation of the three-year cycle.—According to Braak cosmical influences are inadequate to explain the three-year cycle and he shows how it is the result of a self-regulating process, the principal features of which are given below:

1. *Development of the maxima and minima of pressure deviations.*—Low air pressure increases the temperature, especially in the higher air-layers by means of the stronger ascending air movement, which causes an increase of condensation energy. The increase of temperature is in its turn the cause of a further lowering of air pressure. During high air pressure the supply of condensation energy is smaller than normal and the temperature relatively low, by which effect the development of high air pressure is supported. In both cases the effect of pressure and temperature is one of mutual reinforcement.
2. *Change, following the maxima and the minima.*—During the formation of the maximum, a temperature deviation which counteracts the pressure deviation, is developing itself in the lower layers. It is the result of different influences among which the decreased or increased supply of cold air from higher latitudes is probably playing an important part. This pressure deviation is gradually growing stronger until the change sets in.
3. *Passing through the normal state.*—When after the maximum or the minimum the decreasing or increasing air pressure has reached the normal value, it will continue to decrease or increase, because the temperature in the higher air layers is in retard with regard to that in the lower ones.

With reference to the lag above mentioned, the author asks whether this might make the value indicated by t_0 in equation (1) comprehensible and answers the question in the negative because when the higher air layers are in retard as compared with the lower ones this can not give an explanation of the fact that the temperature deviations of the lower air layers lag behind air pressure variations; he prefers the assumption that sea currents with their immense latent heat cause the lag while bearing temperature variations from one part of the globe to another.

Empirical rules for forecasting east-monsoon rains.—The long-range forecast of the greatest importance to agriculture in Java is that of the rainfall that is to be expected in the dry half year running from May to October.

Braak has deduced three empirical rules as follows:

1. The maximum is followed by a year of transition. As maxima should be taken in this case those which follow each other with intervals of three years or more. Those maxima which manifest themselves after an interval of less than three years, for example those of 1904–05 and 1913–14 should be regarded as disturbances and should not be taken into account.
2. When on April 1, following the year of transition, air pressure is below normal, a low pressure year will follow. When a year afterwards air pressure is still below normal another low pressure year will follow, etc.
3. When on April 1 (the transition years sub Figure one [under rule 1] being excluded air pressure is normal, or above the normal, a high-pressure year will follow. (1, p. 40.)

Forecasts made on this basis were successful in the majority of cases. However, the occasional unavoidable failures prompted us to the exercise of greater prudence and the minute inspection of all factors which might have any influence upon the rainfall. Concerning the failures I can not do better than quote the author when he says:

I may recall the forecast given in 1925. Looking at the Port Darwin pressure curve one will immediately recognize 1924 as a year of transition. Now, in January, February, and March, 1925, the monthly mean pressure deviations at Port Darwin and Batavia proved to be

$0.32-1.00-0.34$ mm.

$-1.38-0.63-0.73$ mm. respectively. Application of the second rule yielded the result that a low-pressure year was to be expected and a corresponding wet east-monsoon. However, a sudden rise of the barometer during April, the monthly mean value of the deviation attaining at Batavia $+0.57$ mm. withheld Doctor Braak and the present writer who wished to wait for the Port Darwin value, from giving a monsoon forecast even in the course of May. Finally the Port Darwin mean monthly pressure value of April being known, viz, $+0.07$ mm., and at Batavia yielding a May value $+0.11$ mm., thus showing a decrease after the April maximum, we emitted our monsoon forecast in the first days of June, fortunately much too late for agriculture to take it into account; rainfall would probably be slightly in excess. The east-monsoon of 1925, however, proved to be the driest ever recorded.

I have dwelt upon this case to show how very intricate these questions are and in the second place how dependent we are on the practical circumstances under which the forecasts have to be emitted. If we had known the Port Darwin pressure variation of May, viz, $+0.68$ mm., our forecast would evidently have been better.

Another handicap under which the Javanese forecasters labored was that while as a rule pressure conditions at the beginning of a monsoon season were apt to remain constant, cases arose in which they changed suddenly in the middle of the season.

Two groups of correlation coefficients were computed, the first being between West Java rain in July and August with pressure at Port Darwin, Batavia, Manila and India (for the latter the mean of Calcutta, Madras, and Bombay was used) for the five pairs of months November–December to July–August. The second group correlated West Java rain in September and October with air pressure in the same pairs of months except that an additional pair, September–October was added and for the same stations. Since the coefficients of the second group were in each case greater than those of the first that fact is considered as indicating that the relation between rainfall and air pressure becomes the more intimate as the east-monsoon progresses in its development.

From a consideration of the above and other facts the author concludes that however important Port Darwin pressure may be in the development of the east monsoon, it can not be used as a basis for the rainfall forecast. For that purpose one must use pressure deviations in India, Batavia, and Manila and perhaps one of the soundest bases for the rainfall forecast is the Batavia pressure in the preceding west monsoon. Starting from the formula

$$\Delta R = -a\Delta B \quad \text{(18)}$$

the author develops successive improvements until the final form of equation is reached, as given below:

$$\Delta R = -a\ (\Delta B_1 - 0.5\Delta B_2) + b\Delta T - c\Delta V - k \quad \text{(22)}$$

In the above equation, a, b, and c are empirical positive constants; ΔB_1 is the pressure deviation at Batavia in the west monsoon that immediately preceded the expected east monsoon and ΔB_2 is the pressure deviation at the same place in the west monsoon, that is the *second* west monsoon preceding the expected east monsoon; ΔT is the deviation from the normal of the 9 a. m. Singapore temperature in February, March, and April; ΔV is a measure of the wind direction on the southwest side of Celebes; it is obtained by finding the quotient—

$$\frac{\text{rainfall on windward side Mount Lompoc Batang}}{\text{rainfall on leeward side Mount Lompoc Batang}}.$$

The deviation of this quotient from the normal value gives the factor used in the equation. The constant k is seemingly based on the 6.8-year rainfall cycle of northern Peru and is to be applied only in those years when rains are due according to the cycle. It is applied in the sense that there will be an intensification of the drought in the east monsoon every 6.8 years.

SUMMARY OF RESULTS

1. It seems possible to calculate approximately in the first days of May the rainfall in Java in the second half of the east monsoon, that is in most cases July, August, September, October, by a formula in which the independent variables are only three meteorological elements drawn from stations in the neighborhood.
2. The confidence which that formula inspires is based on the fact that it yields satisfactory results in almost every case of a sequence of 47 years in which control is possible and has yielded the right result the first time it was applied, viz, in 1926.
3. Dry and wet east monsoons are so systematically distributed in a seven-year and a three-year cycle, that even without applying our rainfall formula we are able to indicate correctly at least most of the very dry and very wet ones.

Correction is required in the first place because many sun spots keep pressure lower and east monsoons wetter than normal and few sun spots keep pressure higher and east monsoons drier than normal (regular cases).
4. Some unknown influences may for some time disturb the regular scheme (pathological cases).[1]
5. Sudden rises of pressure and corresponding droughts occur at sun-spot minima (singular cases).
6. Our rainfall formula masters the regular and pathological cases; it is, however, powerless with respect to singular cases, such as the east monsoons of 1913 and 1923.

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[1] The author uses the word "pathological" merely for identification purposes. A used it means years in which some outstanding difference from the results found in normal years appear.

RECENT CONTRIBUTIONS TO HYGROMETRY

By S. P. FERGUSSON

During the past 10 years there has occurred an encouraging increase in the number of investigations and publications relating to hygrometry, a large part of which is due to the growing use of "air-conditioning" processes where the quality of a manufactured product depends upon the control of atmospheric humidity. Of the works reviewed briefly in this note, the papers by Dr. A. Norman Shaw, the "Discussion on Hygrometry" and papers in the "Dictionary of Applied Physics" already are well known to physicists, but are included in order to bring them before the staff of the Weather Bureau.

(1) A. NORMAN SHAW.
IMPROVED METHODS IN HYGROMETRY. (Trans. Roy. Soc. of Canada, Series III, Vol. X, 1916).
RELATIVE HUMIDITY. (In same Transactions, Vol. XI, 1917.)

(2) SIR NAPIER SHAW, EZER GRIFFITHS, F. J. W. WHIPPLE AND OTHERS.
A DISCUSSION ON HYGROMETRY. (Proc. Phys. Soc. London, Vol. XXXIV, 1922.)

(3) S. SKINNER.
HUMIDITY. (Article in "A Dictionary of Applied Physics" by Richard Glazebrook and others, Vol. 3, 1924, published by Macmillan, London.)

(4) GEORGE PORTER PAINE.
THE AERODYNAMICS OF THE PSYCHROMETER. (Annals, Astron. Obs. of Harvard College, Vol. 87, Part 1, 1925.)

(5) ARNOLD ROMBERG and L. W. BLAU.
A NEW HYGROMETER. (Jour. Opt. Soc. of America, Vol. 13, No. 6, December, 1926.)

(6) HERMANN BONGARDS.
FEUCHTIGKEITSMESSUNG. (Published by R. Oldenbourg, München and Berlin, 1926.)

(7) AMAD NATH PURI.
INVESTIGATIONS ON THE BEHAVIOR OF HYGROMETRIC HAIRS. (Quar. Jour. Roy, Met. Soc. Vol. 53, April, 1927.)

(1) The first paper describes experiments with several hygrometers of simple construction which apparently have an accuracy greater than that of instruments in common use. Data are given from two instruments, both of the modified chemical type, one measuring the vapor-pressure and the other the varying weight of a quantity of phosphorus pentoxide; these instruments probably are very satisfactory in the laboratory but are not suitable for continuous use by meteorological observers. Of greater interest and importance to meteorologists is the "Summary of the Limitations of Hygrometric Methods in General Use," based on the author's studies, abstracted as follows:

> The chemical and vapor-pressure methods usually are elaborate and require expert attention and "research" conditions, which, if available and the conditions are constant, admit of determinations of humidity within 0.1 per cent of its true value; but, under ordinary conditions errors of less than 2 or 3 per cent are difficult to eliminate. These methods are almost useless for the examination of a rapidly varying humidity, giving merely the average value during the time of observation.
>
> With dew-point methods, under the most favorable circumstances, an accuracy of greater than 1 per cent can not be assured. If the relative humidity is less than 20 per cent or if the temperature is below 5° C., errors as large as 10 per cent may easily occur.
>
> With the psychrometer, under the best conditions, a good constancy of repetition may be obtained but an absolute accuracy of within 2 per cent can not be assured. If the wet covering and attention to its ventilation are neglected, errors of greater than 5 per cent may develop under apparently normal conditions. If either the relative humidity or the temperature is low, or if the relative humidity is approaching 100 per cent the errors may be larger than 10 per cent. The former conditions for such errors are very common during the winter in cold climates. Inside steam-heated buildings, for example, the relative humidity will, when the temperature is below −30° C. outside, be sometimes as low as 5 per cent and yet be indicated as high as 20 per cent on an instrument which, without alteration, will record satisfactorily under average summer conditions.
>
> Hygrometers of expansion, especially those employing hair, gut, or horn need very frequent recalibrations and in a few months may become almost useless. After subjection to extreme conditions there are often large "after effects" which vary in a complicated manner. If however these instruments are compared frequently with others over a large range of humidities they are the most convenient, because their sensitiveness is great, the time needed for a determination of humidity is short and the procedure merely that of reading a scale or chart. They have, perhaps, been over-maligned by many observers, but it must be admitted that the necessity for frequent recalibration renders them unsuitable for accurate work outside the laboratory.

The second paper discusses from the viewpoint of physics and physiology the confusion due to giving relative humidity and absolute humidity equal prominence and suggests that "treatment of the subject can be kept quite clear if the term 'relative humidity' is kept in its proper place as a derived quantity of secondary importance."

(2) This excellent work, probably the most thorough presentation of modern technique by English authorities, comprises 8 memoirs and 18 short notes in the form of a discussion. An introductory chapter, "The Measurement of Atmospheric Humidity," by Sir Napier Shaw,